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M1 transitions in the SU(3) shell model

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Abstract. M1 transitions in isotopes of Gd and Dy are calculated within the framework of the pseudo-SU(3) model. Basis states are built as linear combinations of direct product SU(3) proton and neutron configurations coupled to total pseudo-spin zero. The system Hamiltonian includes spherical Nilsson single-particle energies, the quadrupole-quadrupole and pairing interactions, as well as four SU(3) symmetry preserving rotor terms. The calculated results compare favorably with the experimental data. The M1 transitions give rise to a unique interpretation of the outer multiplicity that enters in a reduction of the direct product of SU(3) irreducible representations. For comparison, some results for light sd-shell and transitional fp-shell nuclei (e.g. $^{40}$Ne and $^{44}$Ti) are also presented.

The prediction of strongly enhanced M1 transitions within the framework of the so called two-rotor model, introduced in 1978 by Lo Iudice and F. Palumbo [1], has attracted considerable attention over the last several years. While the predominantly orbital character of the magnetic dipole excitation has been confirmed experimentally, other features cannot be explained using a simple two-rotor description. One such feature is the fragmentation of the M1 strength distribution among several levels closely packed and clustered around a few strong transition peaks in the energy region between 2 and 4 MeV in heavy deformed nuclei.

Enhanced low-energy M1 transitions in even-even heavy deformed nuclei have now been observed and some of their characteristic features explained using various models. In particular, the pseudo-SU(3) model with a realistic Hamiltonian [2] has been enGovoked to explore the origin of enhanced low-lying M1 transition strengths in rare earth and actinide nuclei. The theory yields excitation energy that are in excellent agreement (less than 7% error) with the corresponding experimental numbers for $^{159,162,164}$Dy [3] and $^{156}$Gd. Within the pseudo-SU(3) framework, basis states are built as linear combinations of direct product SU(3) proton and neutron configurations coupled to total pseudo-spin zero [4]. The system Hamiltonian includes spherical Nilsson single-particle energies, the quadrupole-quadrupole and pairing interactions, as well as four SU(3) symmetry preserving rotor-like terms [5].

The calculated M1 transition strength distributions for the Dy [3] nuclei are in good agreement with the experimental numbers [6]. The ground states for these nuclei are described by even-even irreducible representations (irreps) of SU(3) which, due to the truncation of the space to $S = 0$ states only, couple to the $1^+$ states through the orbital channel of the M1 operator (Table 1). The total summed M1 strength is slightly lower when a realistic SU(3) symmetry breaking rather than a pure SU(3) symmetry preserving Hamiltonian is employed. This is due to interference generated through the mixing

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A study of M1 transitions in the limit of a pure SU(3) symmetry preserving Hamiltonian yields a unique interpretation of the so-called scissors+twist and twist+scissors modes and their relation to the outer multiplicity that enters in a reduction of the direct product of SU(3) irreps [2, 7]. The total M1 strengths are slightly underestimated, especially for $^{164}$Dy. This may be due to the fact that the present version of the theory suppresses contributions associated with intruder states. Work to enhance the model to include contributions from active intruder configurations is currently underway.

**TABLE 1.** B(M1) strengths from experiment [6] and theory. The columns labelled "pure" are pure symmetry limits of the respective theory. For heavy nuclei "mixed" means the pseudo-SU(3) model with a realistic Hamiltonian [2], and for the light nuclei it means the SU(3) model with spin-orbit coupling. For light nuclei the M1 strengths are given for the full operator along with the separate orbital and spin parts.

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>Experimental $\Sigma B(M1)[\mu^2]$</th>
<th>Theory</th>
<th>pure</th>
<th>mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{156}$Gd</td>
<td>3.40</td>
<td>3.52</td>
<td>1.92</td>
<td></td>
</tr>
<tr>
<td>$^{160}$Dy</td>
<td>2.48</td>
<td>4.24</td>
<td>2.32</td>
<td></td>
</tr>
<tr>
<td>$^{162}$Dy</td>
<td>3.29</td>
<td>4.24</td>
<td>2.29</td>
<td></td>
</tr>
<tr>
<td>$^{164}$Dy</td>
<td>5.63</td>
<td>4.36</td>
<td>3.05</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>pure</th>
<th>mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>total</td>
<td>1.99</td>
<td>3.89</td>
</tr>
<tr>
<td>total L</td>
<td>4.45</td>
<td>1.64</td>
</tr>
</tbody>
</table>

A similar analysis has been carried out for light nuclei, namely $^{20}$Ne and $^{44}$Ti where full 0\hbarω shell-model calculations can be performed. In this case theory is the Elliott SU(3) shell model with spin-orbit coupling. The latter results in strong mixing of several basis states with spin $S = 0$ and $S = 1$ [8]. Specifically, the $J = 0^+$ ground states of $^{20}$Ne and $^{44}$Ti contain both $S = 0$ and $S = 1$ components with the latter giving rise to strong M1 transitions through the spin channel. Note that the total M1 strength due to spin increases slightly when the spin-orbit interaction is included. It is anticipated that the calculated M1 strength will be reduced when a more realistic Hamiltonian is used.

**REFERENCES**